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Technical Note

SIMPLIFIED DATA ANALYSIS FOR AN INEXPENSIVE MANUAL ANALOGUE PENETROMETER

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ABSTRACT

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A simple, rapid, semi-automated digitization method was developed for a microcomputer to aid in the collection and analysis of data obtained from an inexpensive, manual analogue recording penetrometer. Soil strength measurements were taken in a Norfolk loamy sand at Florence, SC using a hand-operated recording penetrometer with a 30°, 12.5 mm diameter cone tip. Three probings were taken at each position within each plot and recorded by pen tracings on an index card. Soil strength readings were taken at 0.1-m spacings across planted rows. Data were read from the cards for each 50-mm depth interval by placing them under the control of a microcomputer and the program "DIGIT". Once initialized for the soil surface, the program automatically moved an eyepiece in the horizontal direction to the position on the card for a specific depth. The operator then moved the eyepiece vertically over the tracings and recorded the data via the digitization process using a flat-bed plotter and microcomputer. These data were averaged over replicates and plotted as isostrength contours using a locally written interpolation plotting routine.

INTRODUCTION

The study of soil strength has been aided by the development of the recording penetrometer, such as the one of Carter (1967). Many of these devices measure resistance to probe penetration with soil depth and record the data on 75 by 125-mm (3 by 5-in) index cards which display profiles of soil strength at a glance. In the Southeastern United States, soil strength has become a valuable parameter in the characterization of dense, root-restricting horizons or pans (Campbell et al., 1974). Penetrometers in general

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have been found useful in a number of other areas including studies of trafficability and load bearing (Duderstadt et al., 1977; Bornstein and Hedstrom, 1982), residual effects of wheel tracks (Billot, 1979; Adams et al., 1982), and soil support and compressibility (Perumpral, 1983).

Computerized penetrometers are currently under development at several locations (Grevis-James, 1983; O'Sullivan et al., 1983; and others). However, many of the older, hand-operated penetrometers remain in use or capable of use, e.g at least 100 from one company alone (D.E. Little, Co., personal communication, 1984). Therefore, as an alternative to computerizing the penetrometer or purchasing a new machine, this paper presents a computer program, "DIGIT", that semi-automates the analysis of data taken with manual, less expensive, card-recording penetrometers. This is accomplished by digitizing the data after it has been recorded on the index cards.

Digitization has proven to be an effective way to enter large quantities of data directly into computer memory by recording a pen location on an electronic table or plotter bed. This may be done with or without processing of the raw data. Individual data points may be recorded as scaled locations relative to benchmarks or boundaries (Sadler and Camp, 1984) or to relative distances in one or two directions. An example of this would be time and rainfall or time and depth to a water table that have been calibrated by standards. As it is used here, digitization involves displacement in two dimensions one of which is depth within the soil (the horizontal direction in Fig. 1a) and the other of which represents the amount of compression of a spring (force), which when divided by the cross sectional area of the probe tip gives stress or cone index.

PREVIOUS METHODS AND TECHNIQUES

For either previous methods or the proposed method, the 3 × 5 card shown in Fig. 1a is scaled in soil depth, the horizontal axis. The scale for the recording penetrometer used here is 1 to 10. Traces shown were taken to a soil depth of 0.55 m, or 55 mm on the recording card, in field plots of different tillage treatments. Soil strengths require calibration also, as shown by the scale in Fig. 1. This scale can be converted by hand or entered into a computer to change a distance into a penetrometer soil strength by multiplying the digitized distance by the strength per unit of distance. For the individual penetrometer that was used in this study, the calibration was linear within the range of strength readings encountered. Readings were obtained with a 30°, 12.5 mm cone tip on a hand-held, analogue recording penetrometer developed by Carter (1967).

Previously, data were read from the cards using a template or scale (see Fig. 1b). One number for each depth of interest was estimated from a set of soil strength measurements taken at the same site (the three curves on each card). The results were entered into the computer for analysis. Digitization of card traces has also been accomplished with a hand-held, freely moving digitizer.

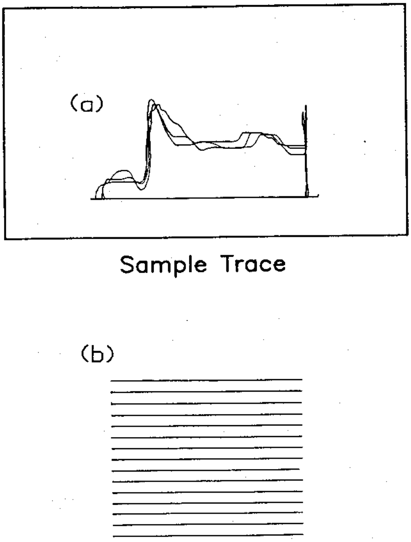


Fig. 1. Sample card showing three traces (a) and the scale (b) of strength for the vertical direction.

CURRENT METHODS AND TECHNIQUES

In the proposed method, cards are placed on a flatbed plotter used as both a digitizer and an eyepiece controller. Raw data are entered into the computer for each of three traces and processed. The method is similar to those used with freely moving digitizers except that here the computer can control some of the eyepiece movement since it is on the bed of a plotter.

At first, the origin (the surface of the soil or some reference such as the top of a board) is digitized. This would be zero, the leftmost point of the trace shown in Fig. 1. Next, the computer automatically moves the eyepiece to the first depth of interest (which may well be the surface itself). The operator then moves the eyepiece vertically over each trace and digitizes the strength. The eyepiece then moves to the next depth, and the sequence is repeated. After the last depth, the baseline is redigitized. If it is not zero, it is assumed that the card is tilted and all points are corrected for the change of strength due to the slope of the line calculated from the origin and the redigitized baseline point. The correction used is:

new reading = old reading $- x*y/d$

where x is the position along the baseline of the strength reading, and d, y are the coordinates of the redigitized baseline point. This method was chosen over the standard rotation of coordinates since it maintained uniform depths which are desirable for statistical analysis. It could lead to errors of the depth readings of the order of 1—2 cm if there are high strength readings; this may be significant for shallow depths. Errors for the strength readings are less than 1.5%. As a result, care needs to be taken when mounting the cards onto the flatbed plotter to get the depth axis as close to the x-direction of the plotter as possible (within ±3 degrees).

The program has an internal error checking routine to detect errors which occur as a result of the digitizing procedure. This is done during data entry, as shown in Fig. 2. It checks for possible negative strength readings which may occur when a zero reading is attempted and for inadvertent changes in depth readings (other than ones required in the program). In either case, the operator is permitted to keep the reading as it stands or correct it for the desired zero reading or the proper depth. At these times, the operator is also given the option of reentering the current depth, the previous depth, or the whole card.

Information is stored in the form of indices for the data (plot no., rep., ...), depth, and soil strength. If depths are standard, strengths alone can be stored.

The program, "DIGIT" (see Appendix) was written in BASIC for the Hewlett-Packard 87XM microcomputer and the Hewlett-Packard 9872A flatbed plotter. Once some experience is gained with the system, cards with three traces can be digitized in as little as 5 min each. This is not much of a time savings over an older system using the template shown in Fig. 1b;

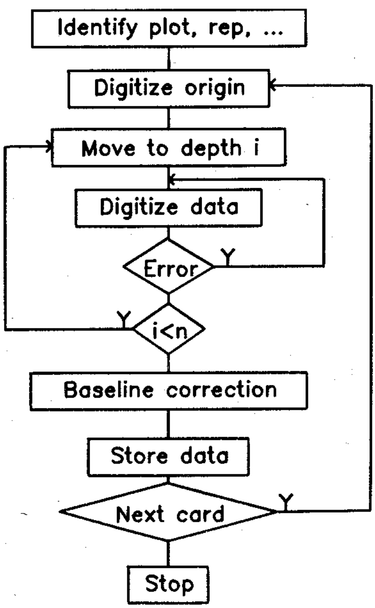
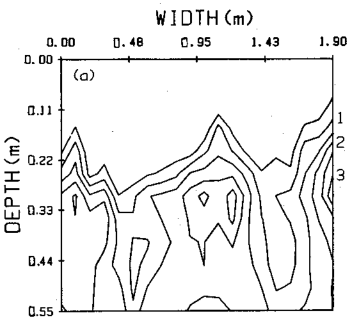


Fig. 2. Schematic of the computer program showing the main parts of the program which digitizes from point 1 to n.

but with this method, data are immediately stored in the computer without further handling and can be partially processed before storage (such as taking the mean of three readings). Digitization as described here or of any other form can increase the accuracy of reading data from the cards by viewing the data through an eyepiece. Of course, the major advantage of the proposed method is the computer control of position along one of the coordinates, the depth, while the operator controls the other, the penetrometer soil strength.

SOIL STRENGTH MAPPING

As an example of how these data have been used, processed information from several cards were combined with a two-dimensional, linear interpolation program to map soil strength readings across two planted rows for two tillage treatments. Examples, shown in Fig. 3, were from tillage treatments in-row subsoiled (a) and chiseled (b). Contours were plotted at 0.5-MPa intervals from 0.5 to 3 MPa. Paths of the subsoil shanks show up clearly in Fig. 3a with the troughs of decreased strength.



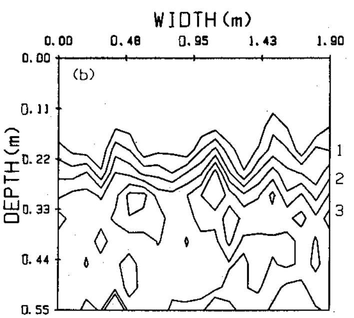


Fig. 3. Cross sections representing approximately two row widths and 0.55 m of depth where (a) has been in-row subsoiled and (b) chiseled. Rows were planted at approximately the 0.5 and 1.5-m positions. Numbers to the right of the plots label the penetrometer soil strength isobars in MPa.

CONCLUSIONS

Recording data using this or any other digitization method reduces the work associated with data collection and analysis from the older, less expensive, manual recording penetrometers by entering data directly into the computer. Some processing such as averages, maximum soil strengths, or conversion from reading to strength can be done as part of the digitizing program.

Digitizing data will increase the accuracy of the readings by eliminating steps of transfer and by viewing the actual data through an eyepiece.

Another advantage of this methodology is that the computer controls part of the movement of the eyepiece by moving it to prechosen depths, and the operator moves the eyepiece in only one dimension to digitize the soil strengths.

The program, "DIGIT", can be easily modified to store color-coded traces as nested subsamples for more extensive statistical analysis.

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APPENDIX

The program "DIGIT"

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10 ! THIS PROGRAM WAS SET UP TO DIGITIZE THE DATA FROM THE 3 x 5 CARDS
20 ! DEVELOPED FROM THE CARTER-TYPE PENETROMETER.  IT ASSUMES 3 TRACES
30 ! PER CARD AND 13 DEPTH LEVELS INCLUDING THE SURFACE(A AND B ARE
40 ! 13 BY 3 MATRICES).  THE DEPTH LEVELS ARE ASSUMED TO BE .5M APART
50 ! ON A SCALE OF 1MM(ON CARD) TO .1M(IN FIELD).  MASS STORAGE IS
60 ! DRIVE 0 AND DATA IS SAVED INTO A FILE NAMED "STDAT" FORMATED AT
70 ! 700 BYTES PER FILE.  EACH CARD IS LOCATED BY A UNIQUE CARD NO.
80 ! WHICH CORRESPONDS TO THE RECORD NO. 1=1041 ON THIS DISC. FILE 361
90 ! KEEPS A RUNNING TOTAL OF THE NUMBER OF RECORDS.
100 ! THE SPRING CONSTANT FOR THE PENETROMETER IS NOT INCLUDED; RATHER
110 ! DISTANCES ARE MEASURED WHICH CAN BE CONVERTED LATER.
120 ! SEE OTHER COMMENT STATEMENTS FOR MORE DETAILS.
130 MASS STORAGE IS ":D700"
140 ASSIGN# 1 TO  "STDAT"
150 READ# 1,361 ; K1
160 DISP "THE LAST CARD DIGITIZED IS";K1
170 OPTION BASE 1
180 DIM A(13,3),B(13,3)
190 ! INPUT THE CARD NUMBER THAT YOU ARE WORKING ON. THEN
200 ! INPUT THE IDENTIFICATIONS OF THE VARIOUS TREATMENTS IN THE
210 ! ORDER PLOT NO., WIDTH IN ROW, DATE OF SAMPLING, TREATMENT.
220 DISP "WHICH CARD NUMBER ARE YOU WORKING ON?"
230 DISP "IF YOU WISH TO STOP SET CARD NO.= -1."
240 INPUT N
250 N=N-1040 ! NO. OF CARDS DIGITIZED ON OTHER DISKS.
260 IF N<0 THEN GOTO 900
270 DISP "IF YOU WISH TO STOP SET NO1=-1 AND ANY NO FOR OTHERS"
280 DISP "FIELD NO., WIDTH, PLOT NO., DATE"
290 INPUT NO1,WIDTH,NO2,DA
300 IF NO1<0 THEN GOTO 900
310 DISP "WORKING ON CARD NO.",N+1040
320 IF N+1040=1720 THEN DISP "*** THIS CARD WILL FILL THE DISC. ***"
330 IF N+1040>1720 THEN DISP "*** THE DISC IS FULL. ***"
340 DISP "FIELD NO.,DISTANCE ACROSS THE ROW,PLOT NO.,DATE"
350 DISP NO1,WIDTH,NO2,DA
360 ! IF Y<0 THEN THE SYSTEM LOOKS FOR A POSSIBLE NEGATIVE READING
370 ! OR A CORRECTION TO THE DIGITIZING PROCESS. SEE LINES 1490-1590.
380 PLOTTER IS 705  ! DEFINES THE FLAT BED PLOTTER.
390 DISP "THE ORIGIN IS"
410 DIGITIZE D0,Y0,P  ! COORDINATES AND 'PEN' STATUS.
420 IF P=0 THEN 960
430 LOCATE D0,D0+100,Y0,Y0+60 ! DEFINES PLOTTER FIELD.
440 MSCALE 0,0 @ BEEP 230,10  ! SCALES PLOTTER TO MM.
450 Y=0       ! ^ @ ALLOWS STATEMENT CONCATENATION
460 I=1
470 DRAW (I-1)*5,Y @ DISP (I-1)*5,Y
480 FOR J=1 TO 3
490 K=0
500 ! NOTE: YOU MUST DIGITIZE WITH THE PEN DOWN.
510 DIGITIZE D,Y,P
520 IF D<> (I-1)*5 THEN 1140
530 IF P=0 THEN GOTO 920
540 IF Y<-.00001 THEN 990
550 IF K=0 THEN 570
560 ON K GOTO 570,470,640,380,570
570 A(I,J)=D @ B(I,J)=Y
580 DISP I,J,A(I,J),B(I,J) @ BEEP 230-I*10,10
590 NEXT J
600 MOVE D,Y
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610 IF I=13 THEN 700
620 I=I+1
630 GOTO 470
640 I=I-1
650 MOVE D,Y
660 Y=0
670 GOTO 470
680 ! THE FOLLOWING FEW LINES CORRECT FOR A NON-PARALLEL
690 ! BASE LINE UNLESS THE CORRECTION IS LESS THAN .001.
700 DISP "REDIGITIZE THE BASE LINE HERE."
710 DRAW 60,0
720 DIGITIZE D,Y,P @ IF P=0 THEN 940
730 IF Y>75 THEN 470
740 DISP D,Y @ BEEP 230,10
750 MOVE D,0
760 PLOT 160,0,1
770 PEN UP
780 IF ABS (D)<.001 THEN 840
790 FOR I=1 TO 13
800 FOR J=1 TO 3
810 B(I,J)=B(I,J)-(I-1)*5*Y/D
820 NEXT J @ NEXT I
830 ! CREATE "STDAT",M,700 FOR A DISK BASED FILE OF M CARDS.
840 PRINT# 1,N ; NO1,WIDTH,NO2,DA,A(,),B(,)
850 K=0
860 IF N>2 THEN READ# 1,361 ; K
870 IF N+1040>K THEN PRINT# 1,361 ; 1040+N
880 N=N+1
890 GOTO 280
900 ASSIGN# 1 TO  *
910 STOP
920 DISP "PLEASE, PUT THE 'PEN' DOWN."
930 GOTO 510
940 DISP "PLEASE, PUT THE 'PEN' DOWN."
950 GOTO 720
960 DISP "PLEASE, PUT THE 'PEN' DOWN."
970 GOTO 410
980 DISP "CHOOSE A NUMBER BETWEEN 0 AND 4"
990 K=15
1000 DISP "YOU HAVE MOVED BELOW THE ZERO STRENGTH AXIS TO ";Y
1010 DISP "DO YOU WANT 0-A ZERO READING"
1020 DISP "                1-A NEGATIVE READING"
1030 DISP "                2-TO REDO THIS STEP"
1040 DISP "                3-TO MOVE BACK TO THE PREVIOUS STEP"
1050 DISP "                4-TO START THE CARD OVER AGAIN"
1060 INPUT K
1070 IF K<0 OR K>4 THEN 980
1080 IF K=0 THEN PLOT D,0,1
1090 IF K=0 THEN Y=0
1100 IF K=1 THEN PLOT D,Y,1
1110 GOTO 550
1120 DISP "CHOOSE A NUMBER BETWEEN 1 AND 5"
1130 K=15
1140 DISP "YOU HAVE MOVED ON THE DEPTH AXIS TO";D
1150 DISP "                1-IT IS SUPPOSED TO BE AT THIS DEPTH"
1160 DISP "                2-REDO THIS STEP"
1170 DISP "                3-MOVE BACK TO THE PREVIOUS STEP"
1180 DISP "                4-START THE CARD OVER AGAIN"
1190 DISP "                5-REDO JUST THIS DIGITIZATION"
1200 INPUT K
1210 IF K<1 OR K>5 THEN 1120
1220 IF K=1 THEN 530
1230 IF K=5 THEN PLOT (I-1)*5,Y,1 @ GOTO 510
1240 GOTO 540
1250 END
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